Exposure Variability and Image Quality in Computed Radiography

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Purpose To evaluate the effect of a wide range of exposure techniques on the overall quality of the computed radiography (CR) image.

Methods A Fuji FCR 1 Shot QC Phantom was exposed to mAs values ranging from 1 to 125, yielding 8 exposure groups. Five CR imaging plates were exposed, processed and printed for each exposure group. Image quality was evaluated by measuring the optical density, density differences and number of line pairs visualized.

Results The findings indicate that variability in radiation exposure to the CR imaging plate does not adversely affect the quality of the digital image. Optical density and low-density differences were stable throughout the wide range of exposures. Radiographic contrast appeared to decrease for the high-density differences when exposed to higher-than-needed exposures, and resolution appeared to be compromised at extreme low-radiation exposures.

Conclusion The results of this experimental study are consistent with the digital imaging literature in that a radiation exposure technique above or below the optimum level will produce a diagnostic-quality image. Radiographers must become more knowledgeable about digital imaging systems so they can produce quality images with the least amount of exposure to their patients.

Digital imaging rapidly is becoming the standard in diagnostic radiology. Several different types of digital image receptors (IRs) are used today, including cassette-based, computed radiography (CR) and cassetteless, direct digital radiography (DR) systems. A significant advantage of digital IRs compared with film-screen receptors is the wide dynamic range of radiation intensities that can be detected. Film-screen receptors are inherently limited in their ability to detect this wide range of exit radiation intensities to produce a diagnostic-quality image on film. Digital IRs can detect a much wider range of radiation intensities exiting the patient and digitally process this information for viewing on a display monitor.

Because digital data can be processed after acquisition, adjustments for exposure technique errors are common. Whether the radiation exposure to the digital IR is low or too high, adjustments can modify the radiographic density. Although the ability to correct for exposure technique errors has been a remarkable advantage to radiographers, making postacquisition adjustments also has disadvantages.

Low exposures to the IR produce diagnostic radiographic densities but have overall poor quality due to the increased quantum noise visualized on the digital image. Some radiographers have attempted to overcome the problem of quantum noise by increasing the overall amount of radiation exposure, thereby resulting in a common practice known as exposure factor creep. Although digital imaging can reduce the number of repeat images, more radiation is needed to produce a CR image of similar quality to a film-screen image. Consequently, many radiographers increase the quantity of radiation reaching the IR to improve CR image quality. This, in turn, has raised concern in the industry about the need to better educate radiographers, radiologists and other physicians on the potential for increased radiation exposure to patients with CR.

Our lack of knowledge about the various types of digital IRs and the ability of IRs to detect exit radiation has recently been identified as an important professional issue. In addition, because medical imaging is the largest single source of radiation exposure outside of natural or background exposure, efforts must continue to minimize this exposure to the public. It is well documented that digital IRs can compensate for exposure variability, but it is not known whether there is a limit to overexposure at which digital image quality is compromised. This important issue led to the current research study on radiation exposure variability and its effect on digital image quality.
IMAGE QUALITY IN COMPUTED RADIOGRAPHY

**Literature Review**

It is well documented that digital imaging technologies can compensate for under- and overexposure.  

According to Vano, “For digital detectors, higher doses result in a better image quality (ie, a less-noisy image) in a certain range of dose.” However, low radiation exposures increase the amount of quantum mottle (noise) visible on the image and “observers complain about the noise in CR images exposed at ¼ to ½ of an appropriate level.” It also is believed that overexposures in CR imaging can result in decreased contrast.

CR has a wide dynamic range, which enables the image to display a greater range of radiographic densities in response to both low and high exposures. CR’s ability to compensate for exposure errors, which is more than 300 to 400 times greater than that of film-screen imaging, results in decreased repeat images. However, the wide dynamic range of CR also has led to the realization that radiographers may not be as precise in selecting optimal exposure techniques. Additionally, Vano stated that “the increase in dynamic range of the digital imaging system makes it more difficult to recognize overexposure or underexposure.”

Warren-Forward and colleagues conducted a retrospective analysis of exposure indices for chest and lumbar exams at 2 hospitals to determine whether radiographers were selecting exposure techniques within the manufacturer’s guidelines. Their findings indicated that a high percentage of exposure indices were outside of the recommended range for both hospitals, indicating that over- and underexposures had occurred. The authors believed that these findings indicate a need for more education and training.

Compagnone and colleagues investigated differences between film-screen, CR and DR radiation exposures for several standard radiographic procedures and found that CR generally resulted in higher effective skin dose than did film-screen radiography or direct digital radiography. Although there was an increase in patient exposures using the CR system, the authors acknowledged that because of the system’s dynamic range, overall repeats caused by exposure technique errors were reduced.

Concerns regarding overexposure in pediatric imaging also have been emphasized in the literature. According to an editorial by Willis and Slovis, “Research indicates an increased risk of childhood acute lymphocytic leukemia from plain film studies and an increased risk of fatal breast cancer from scoliosis series.” Because children are more radiosensitive than adults and they have a longer life span, efforts to reduce their radiation exposure is of even greater importance.

Evidence also suggests that there is an increase in utilization of the new digital technologies due, in part, to operational improvement in radiology imaging services, such as quicker access to images and decreased turnaround time for radiographic reports. As a result, some experts argue that this increase in utilization of digital imaging contributes to increased patient radiation dose. Because medical uses of ionizing radiation account for more than 95% of radiation exposure from man-made sources and because there is a potential for increasing use of diagnostic imaging, radiographers must be more aware of the effect of radiation exposure on image quality and patient dose.

Ionizing radiation in the form of x-rays has been identified by the Department of Health and Human Services as a known human carcinogen: “Epidemiological studies of radiation exposure provide a consistent body of evidence for the carcinogenicity of X-radiation and gamma radiation in humans.” The generally accepted estimate of risk due to low-dose exposure is the linear nonthreshold model that indicates risk exists with even the lowest amount of exposure. A high-profile national organization, The National Academies, released new information that supports the belief that low levels of radiation might cause harm. According to Brenner et al, “The most reasonable assumption is that the cancer risks from low doses of x- or y-rays decreases linearity with decreasing dose.” This further validates the linear nonthreshold risk model that has been debated over the years.

Accurately determining radiation-induced cancer risk in humans is difficult because of biologic variability, environment and lifestyle-related factors. Although consensus has not been reached over the risk of low-level radiation exposure, evidence suggests that it is a legitimate concern, especially in an era when increased radiation exposure is a real possibility. In addition to limiting dose to patients, some practitioners are calling for guidelines to limit the number of high-quality images. Adjusting exposure technique in cases where the exam does not require a high-quality image, such as routine follow-up exams, can result in a decrease in overall patient exposure.

It is imperative that operators of ionizing radiation-emitting equipment become better educated to meet the demand for quality radiographic images with the lowest possible exposure to the patient. Radiographers must adhere to the ALARA (as low as reasonably achievable) principle to ensure that the benefit of patient radiation exposure outweighs the risk.
Exposures were made using varying amounts of radiation. Five 14 x 17-inch Fuji Smart CR IPs (type C) were used throughout the experiment to capture the images of the phantom test tool. The IPs were processed using the test mode in a Fuji FCR XG-1 Smart CR reader (Tokyo, Japan), and hard copy images were printed by a FujiFilm FM DPL laser printer (Tokyo, Japan). Optical densities were measured using the X-rite densitometer model 301 (Grandville, Michigan). The baseline phantom images were exposed and processed according to the specifications in the Fuji FCR quality assurance program manual. Each IP was processed in the Fuji Smart CR reader using the "test" mode, and no manual processing was performed. Five images were exposed, processed and printed to obtain an average baseline for the optimal exposure technique, which was determined to be 8 mAs. All 5 baseline CR IPs were

**Purpose**

An investigation of the effect of insufficient and excessive radiation exposure on CR image quality is an initial step to better understanding this digital technology. The ultimate goal is to reduce patient exposure to radiation while maintaining the image quality required for the exam.

This study evaluated the effect of a wide range of exposure techniques on the overall quality of the CR image. The purpose of this study was to determine how extreme variation in the quantity of radiation incident on the CR imaging plate (IP) would affect the exposure indicator, optical density, measured density differences (radiographic contrast) and number of line pairs visualized (resolution).

**Methods**

The research study used an experimental design to investigate the effect of varying the quantity of radiation exposure on CR image quality. The independent variable was the amount of radiation incident on the CR IP. The radiation quantity was varied by changing the time of exposure to increase or decrease the milliamperage-seconds (mAs). The dependent variable (ie, radiographic quality) was evaluated by measuring on the printed CR image the optical density and density differences for low and high contrast and visually assessing the number of line pairs. In addition, the exposure indicator was documented by the sensitivity (S) value provided during CR image processing.

**Equipment**

A General Electric MVP 60 3-phase routine radiography generator (Milwaukee, Wisconsin) was used to expose the IPs. A variety of quality control tests (exposure reproducibility and linearity, kilovoltage accuracy, exposure timer verification and laser printer-quality control sensitometry) were performed on the radiographic system prior to initiating the study. All tests indicated the imaging system was functioning properly.

A Fuji FCR 1 Shot QC Phantom (Stamford, Connecticut) was used because it provides an image to evaluate and monitor the CR system components with 1 exposure (see Figure 1). The phantom test tool is a 14 x 17-inch plate constructed to measure system parameters such as sensitivity calibration, contrast, image noise, linearity and sharpness.

Exposures were made using varying amounts of radiation. Five 14 x 17-inch Fuji Smart CR IPs (type C) were used throughout the experiment to capture the images of the phantom test tool. The IPs were processed using the test mode in a Fuji FCR XG-1 Smart CR reader (Tokyo, Japan), and hard copy images were printed by a FujiFilm FM DPL laser printer (Tokyo, Japan). Optical densities were measured using the X-rite densitometer model 301 (Grandville, Michigan). The baseline phantom images were exposed and processed according to the specifications in the Fuji FCR quality assurance program manual. Each IP was processed in the Fuji Smart CR reader using the “test” mode, and no manual processing was performed. Five images were exposed, processed and printed to obtain an average baseline for the optimal exposure technique, which was determined to be 8 mAs. All 5 baseline CR IPs were
Results

Table 2 shows the mean values obtained for each dependent variable, exposure indicator, optical density, density differences and line pairs per millimeter as a result of variability in the radiation exposure.

Exposure Indicator

The exposure indicator value (the S number) is inversely proportional to the amount of radiation incident on the CR IP. As the radiation exposure doubles, the S number approximately halves its value. Conversely, as the radiation exposure halves, the S value approximately doubles in value.

The acceptable variability of the exposure indicator value on the CR system used in this study should be within 15% of the expected value for changes in the incident radiation exposure.

The 5 exposure indicator values for the 1 mAs group showed the greatest amount of variability, ranging from a low of 1746 to a high of 1915. However, the overall mean of the S value for the lowest exposure group was still within the 15% range of variability. The S value mean for the high exposure groups was within 1 point of the expected value, indicating that the exposure indicator is stable over a wide range of radiation exposures above the optimal baseline value. All of the exposure groups were within the limits of variability as stated by the manufacturer of the QC test tool.

Optical Density

The optical density measured for all of the exposure groups yielded very little variability. The mean value
range from 1 mAs to 125 mAs radiation exposures was 1.4 at its lowest to a high of 1.432 (see Figure 2). The change in optical density for the extreme change in radiation exposures was only 0.092 (2%). Given that a change in optical density of 0.15 is an acceptable variability in optical density for film-screen processing quality control, the current study found optical density to be maintained for extreme exposure variations to the CR IPs.

### Density Differences

The Fuji FCR QC test tool has beam-attenuating circles for measuring both high and low optical density differences, thereby providing information about radiographic contrast. The low optical density differences yielded no change in value from 1 mAs to 125 mAs, indicating no variability. However, the high density difference circles showed a relatively consistent decrease in the optical density difference value as the mAs value increased from 8 mAs to 125 mAs (see Figure 3).

### Resolution

Visibility of the line pairs per millimeter was more difficult in the lower exposure ranges when compared with the digital images exposed at the baseline and higher exposures. Image noise as a result of quantum mottle or low photon energy was more visible in the low radiation exposure groups.

Overall, the findings indicated that variability in radiation exposure to the CR IPs did not affect the quality of the digital images adversely. Optical density and low-density differences were stable throughout the wide range of exposures and the exposure indicator was within the limits of variability for all exposure groups. Radiographic contrast appeared to decrease for the high density difference circles when exposed to higher-than-needed exposures, and resolution appeared to be compromised at extreme low-radiation exposures.

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**Table 2**

Mean Values for the 8 Exposure Groups

<table>
<thead>
<tr>
<th>mAs Groups</th>
<th>Exposure Indicator (S value)</th>
<th>Optical Density</th>
<th>Low Density Difference</th>
<th>High Density Difference</th>
<th>Number of Line Pairs Per mm Visualized</th>
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<tr>
<td>1</td>
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<td>1.420</td>
<td>.3</td>
<td>.838</td>
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<td>.868</td>
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<td>13</td>
<td>1.432</td>
<td>.3</td>
<td>.776</td>
<td>2.875</td>
</tr>
</tbody>
</table>

* Each mAs group comprised 5 exposures.

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**Discussion**

The results of this experimental study are consistent with the digital imaging literature in that a radiation exposure above or below the optimum level will produce a diagnostic-quality image. However, extreme high-radiation exposures will decrease radiographic contrast and extreme low exposures will decrease resolution.

Consistent with the literature, the optical density was stable over radiation exposures that ranged from 300% lower to 400% higher than the optimal baseline mAs exposure. Radiographic contrast appeared to decrease at the highest radiation exposure. This could indicate that overexposure to the CR IP results in lower contrast. It is believed that excessive radiation exposure to the IP will cause saturation that results in a system’s inability to compensate; therefore, differences in optical density or contrast will be minimized. In addition, the ability to visualize line pairs per millimeter was decreased for the extreme low-radiation exposures. Insufficient radiation exposure to the CR IP will result in computer adjustment to maintain optical density, albeit with an increase in quantum mottle or noise. Noise on the digital image will limit the visibility of recorded detail.

The exposure indicator was adjusted appropriately for changes in radiation exposure to the IP. The baseline S value showed an appropriate inverse proportional relationship to the higher and lower radiation exposures. However, the S value showed a greater variability than expected at the most extreme low-radiation exposures.
accurately reflect changes in image quality for actual patient radiation exposures. To evaluate system linearity, the exposure to the CR IP should have been increased by actually exposing the IPs multiple times. This study altered the mAs value to expose the IPs to increased exposure. It is not known how image quality would have been affected if the mAs value remained constant and the IPs had been exposed by a factor of 2 for the extreme radiation exposure groups.

It is, therefore, recommended that future research studies be performed to further validate how extreme variation in radiation exposure affects digital image quality. For example, this study could be replicated on different types of digital imaging equipment. Additionally, a patient-equivalent phantom could be used to produce digital images, which then could be evaluated for quality. Using a patient-equivalent phantom would create a more realistic imaging study to assess over- and underexposure and the resulting effect on optical density, contrast and resolution. It also would be worthwhile to have radiologists evaluate the display monitor quality of digital phantom images exposed to a wide range of radiation exposures to determine whether the ability to diagnose is compromised.

**Conclusion**

The findings of this study confirm that extreme variability in radiation exposure will produce diagnostic-quality digital images. Thus, it is even more important for radiographers to recognize the relationship between radiation exposure and image quality for digital imaging systems. Intentionally or unknowingly overexposing patients is an objectionable practice. Radiographers must become more knowledgeable about digital imaging systems so they can produce quality images with the least amount of exposure to patients. It is solely the radiographer’s responsibility to determine the appropriate amount of radiation exposure needed to produce a quality digital image for diagnosis. As imaging professionals, we must not underestimate our role in ensuring that our patients receive the utmost care.

**References**


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